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THE EFFECTS OF COLOR-CODING INDICATOR ON DARK ADAPTATION

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ABSTRACT

Utilization of complex systems is handicapped by lighting requirements for dark adaptation of personnel. An experiment was conducted to compare reaction times to color-coded indicators under red, nominal white and normal white ambient lighting. Subsequent analysis shows that poorest performance was obtained under red ambient illumination. Visual acuity tests indicate that dark adaptation is primarily dependent upon the overall illumination level rather than upon red lighting. Results tend to prove that an illuminated indicator display color has little effect on dark adaptation, and that certain indicator colors are more quickly detected than others. Recommendations are made for optimal and alternate lighting and indicator color combinations.

Letter on file

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1.0 DISCUSSION OF THE PROBLEM

One of the dilemmas confronting contractors developing sonar systems is the apparent conflict between the requirements for the use of red lighting on indicator displays solely to maintain personnel dark adaption and the requirement for color coding indicator displays for effective operation of the highly complex sonar equipment. To further confuse the issue, the requirements for total dark adaptation in the sonar room has been questioned. Presently, the sonar control room is fitted with both red and white ambient lighting and it is at the discretion of the commanding officer as to which is employed. Some sources, such as Craik and Vernon[1] and Howard[2], feel that a more realistic requirement for the sonar control room would be for low level white ambient illumination (dim-out) under glare-free conditions for enhancing contrast and visibility of sonar displays, rather than low level red ambient illumination for total dark adaptation (blackout) and the subsequent need for all indicators to be red lighted.

Based upon present fleet experience, there are three distinct types of ambient lighting conditions employed under operational conditions:

1. Normal white ambient illumination in the 20-50 foot-candle range utilized in the sonar control room and the attack center during the daytime at the discretion of the commanding officer and in the equipment room at all times.
2. Nominal white ambient illumination in the .02 foot-candle range employed in the attack center.
3. Red ambient illumination in the 0.01-0.04 foot-candle range employed in the Sonar Control Room for general dark adaptation of sonar personnel, and in the attack center to maintain dark adaptation of the navigation, fire control personnel and so that the conning officer can observe sonar displays prior to night surfacing or using the periscope at night.

Currently, sonar displays are provided with red illuminated controls only. The one exception, is the Bearing Time Recorder which may be illuminated with either red or white illumination by manually inserting a filter.

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[1] References are listed on page 4-2.

Since the ambient lighting requirements and the control-display illumination requirements are not identified for the AN/BQQ-1 Sonar System in the present equipment specification (MIL-E-16400),[3] it is the purpose of this study to provide experimental data to aid in the definition of these requirements. This study was initiated to determine the effect of employing color-coded illumination on indicator pushbutton displays on dark adaption under red, nominal white, and normal white ambient lighting. This experiement was accomplished by varying the intensity of the ambient and display indicator illumnation.

2.0 METHOD OF EXPERIMENT

2.1 Apparatus

The study was conducted in the electrical engineering dark room employing red ambient illumination of 0.02 foot-candles, nominal white illumination of 0.02 foot-candles and normal white illumination of 20 foot-candles. The display panel shown in Figure 1 is 19 by 11 inches and contains three rows of ten Master Specialty Twist-Lite horizontally-split illuminated push-button indicators. The top half of push-button indicators was always illuminated. The experimenter has the capability of illuminating the bottom half of each of the thirty indicator push-buttons by means of a series of rotary switches located on the experimenter's control panel.

A clock, placed in series with these switches, measured the time interval between the illumination of the indicator by the experimenter and extinguishing the light by the subject. The lenses and display screens could be changed from the front of the panel and consisted of two separate sets. One set contained all red horizontally split display screens, one-third with translucent lenses with black engraving and two-thirds with opaque black lenses with translucent engraving. The second set consisted of ten equal sub-sets of display screens which were red, amber, green, white, red and amber, red and green, red and white, amber and green, amber and white, and green and white. Within each sub-set, two push-buttons were fitted with black opaque lenses with translucent engraving and one with a translucent lens with black engraving. The illumination of the push-button indicators was controlled by a Nobatron voltage regulator. The illumination of the indicators was controlled, so that under the red and nominal white ambient conditions the translucent lens provided a 0.3 foot-candle output and the black opaque lens a 0.03 foot-candle output. Under the normal white ambient condition, the transparent lens provided 3.0 foot-candle output while the opaque provided 0.3 foot-candles.

2.2 Subjects and Procedure

Eighteen male subjects from the Raytheon engineering organization, ranging in age from 21 to 32, with at least 20/30 uncorrected visual acuity were divided into three

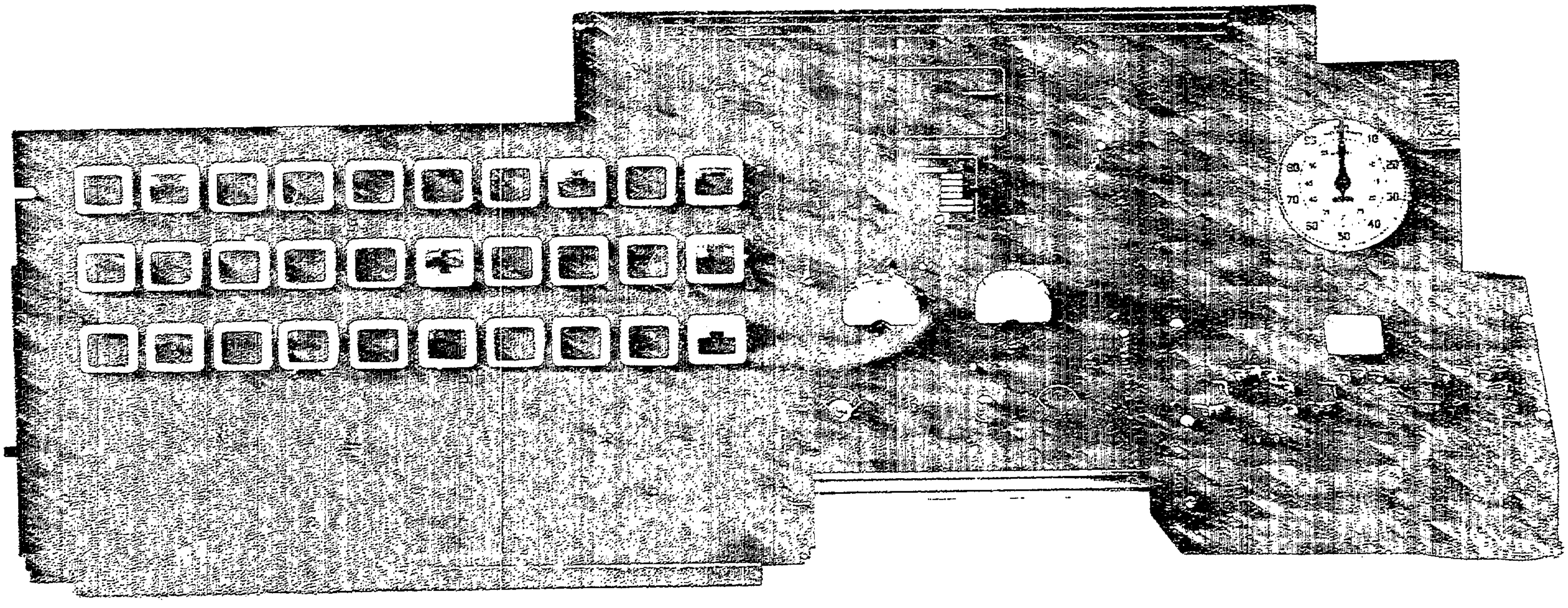

FIGURE 1 EXPERIMENTAL EQUIPMENT SHOWING DISPLAY PANEL, VOLTAGE REGULATOR, CLOCK AND EXPERIMENTERS CONTROL PANEL

equal groups. Group 1 and 2 remained in the experimental room under red ambient lighting for a period fo twenty minutes to insure maximum dark adaptation. Group 3 spent an equal time interval under normal white ambient light. During this waiting period, all directions and explanations were presented to the subjects. At the end of this period, each subject was given a modified Ortho-Rater visual acuity test. For Group 2 the red ambient was changed to a nominal white ambient and they were retested immediately. The modified Ortho-Rater visual test consisted of a checkerboard pattern viewed on a card rather than through the Ortho-Rater. The size of the pattern and distance of the pattern to the subject is identical to the Ortho-Rater presentation. Following the visual acuity test, each group was required to identify the push-button indicator illuminated by the experimenter by depressing the indicator, thereby extinguishing it. The order of presentation was randomized with respect to the presentation of both red and colored indicators. Each subject was presented with thirty trials under each condition. The time required to depress the appropriate push-button indicator was recorded after each trial. At the conclusion of each presentation consisting of thirty trials, the visual acuity test was repeated.

3.0 RESULTS OF EXPERIMENT

The reaction time: i.e., the time between the illumination of the push-button indicator by the experimenter and the extinguishing of the lighted indicator by depression of the push-button by the subject, was analyzed to determine the effects of the three ambient lighting conditions, colored and red display screens and the position of the individual display screens. Table 1 summarizes the results of the analysis of reaction

TABLE I ANALYSIS OF VARIANCE OF REACTION TIMES

Source	Degrees of Freedom	Mean Square	Level of Significance
Ambient Lighting	2	.1293	49.7**
Display Screen Color (Red vs. Colored)	1	.0066	2.53
Position	29	.0052	2.00*
Ambient Screen Color	2	.0077	2.96
Ambient X Position	58	.0027	1.03
Display Screen Color X Position	29	.0029	1.11
Error	58	.0026	
	Total 179		

** P. (Probability) < .001
 * P. (Probability) < .05

The results of this analysis demonstrate that the type of ambient lighting employed significantly effects performance. This is shown graphically in Figure 2. Poorest performance, i.e., the ability to locate and extinguish the illuminated lower half of the push-button indicator, occured under red ambient illumination (mean reaction time 2.16 seconds): intermediate performance was found under nominal white ambient illumination (mean reaction time 1.71 seconds): and maximal performance occurred under normal white ambient illumination (mean reaction time 1.23 seconds).

As was expected, the position of the indicator significantly affected reaction time. Figure 3 shows that the indicator push-buttons located in the first three and last three positions on each row required a significantly longer reaction time than the four center

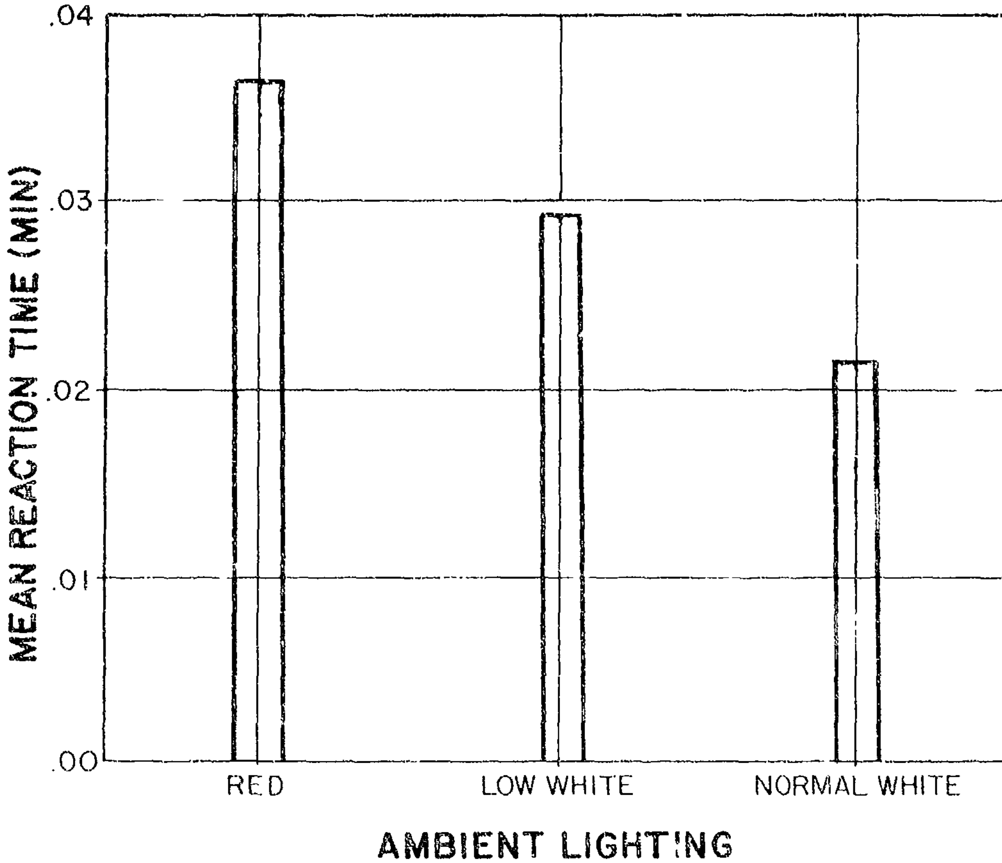

FIGURE 2 EFFECT OF AMBIENT ILLUMINATION OF REACTION TIME

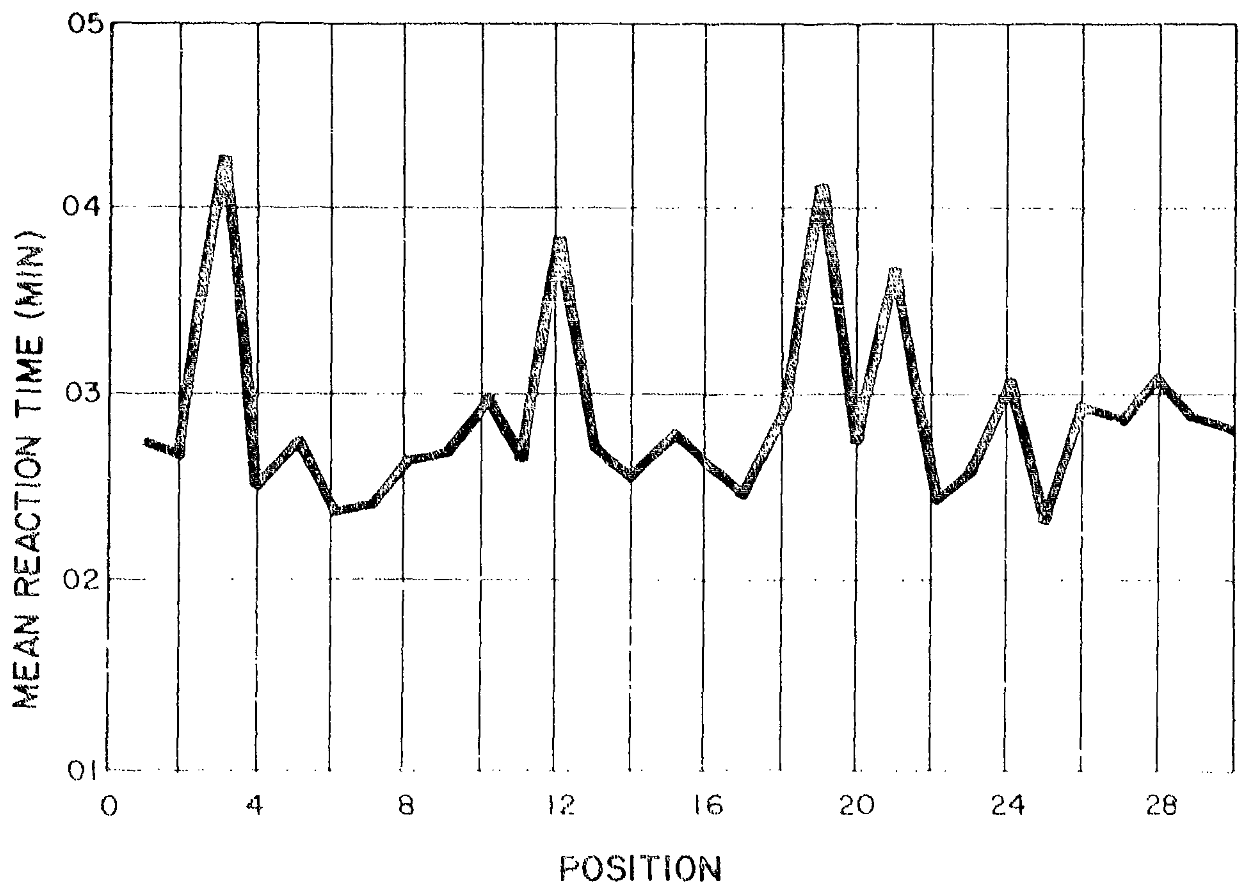

FIGURE 3 EFFECT OF POSITION ON REACTION TIME

positions in each row. Although the highest reaction times occurring at the periphery were responses to the black opaque lenses, this was not significant in the analysis.

The reaction times for operation of the colored lights was subjected to a separate analysis of variance to determine the effects of the four colors (red, amber, green, and white), and type of lens (opaque or translucent) upon reaction time. This analysis is summarized in Table II.

TABLE II ANALYSIS OF VARIANCE OF REACTION TIMES FOR COLORED LIGHTS

Source	Degrees of Freedom	Mean Square	Level of Significance
Ambient Lighting	2	.0185	11.56*
Color	3	.0011	NS
Lens	1	.0005	NS
Ambient X Color	6	.0008	NS
Ambient X Lens	2	.0008	NS
Color X Lens	3	.0009	NS
Error	6	.0016	
	Total 23		

* P. (Probability) < .01

Inspection of Table II shows the effect of ambient lighting to be significant; however, neither the effect of screen color nor lens is significant. Closer inspection of the effect of color on reaction time, as shown in Figure 4, shows that there is significant effect of color display screen under the red ambient lighting condition ($P < .05$); however, this effect is masked by the two other ambient conditions in the over all analysis. Under red ambient conditions, reaction times in increasing order were amber, green, red and white. This order was also maintained under normal white ambient illumination; however, under nominal white ambient lighting, the reaction times for the four colors were almost identical.

Figure 5 shows that decreasing the ambient illumination from the normal white lighting of 20 foot-candles, to either the nominal white or red ambient lighting of

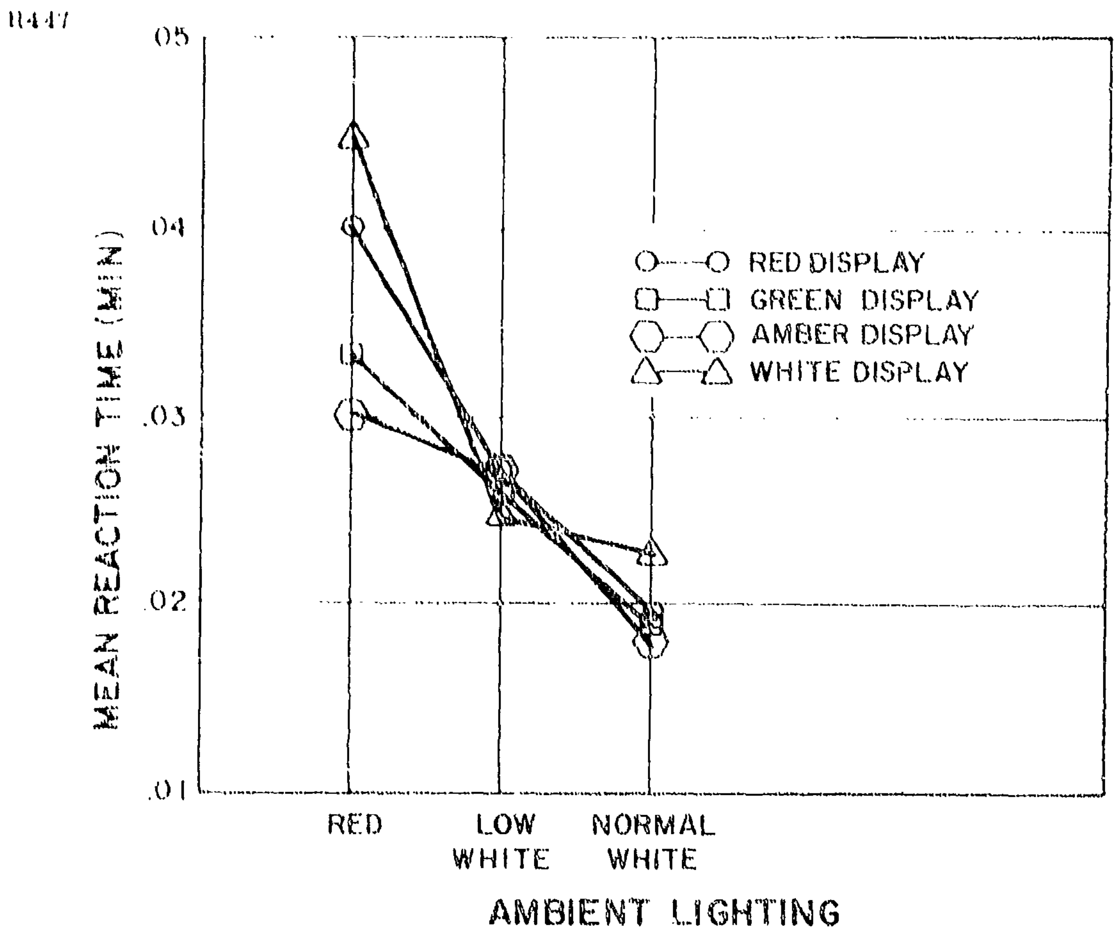

FIGURE 4 EFFECT OF DISPLAY SCREEN COLOR ON REACTION TIME

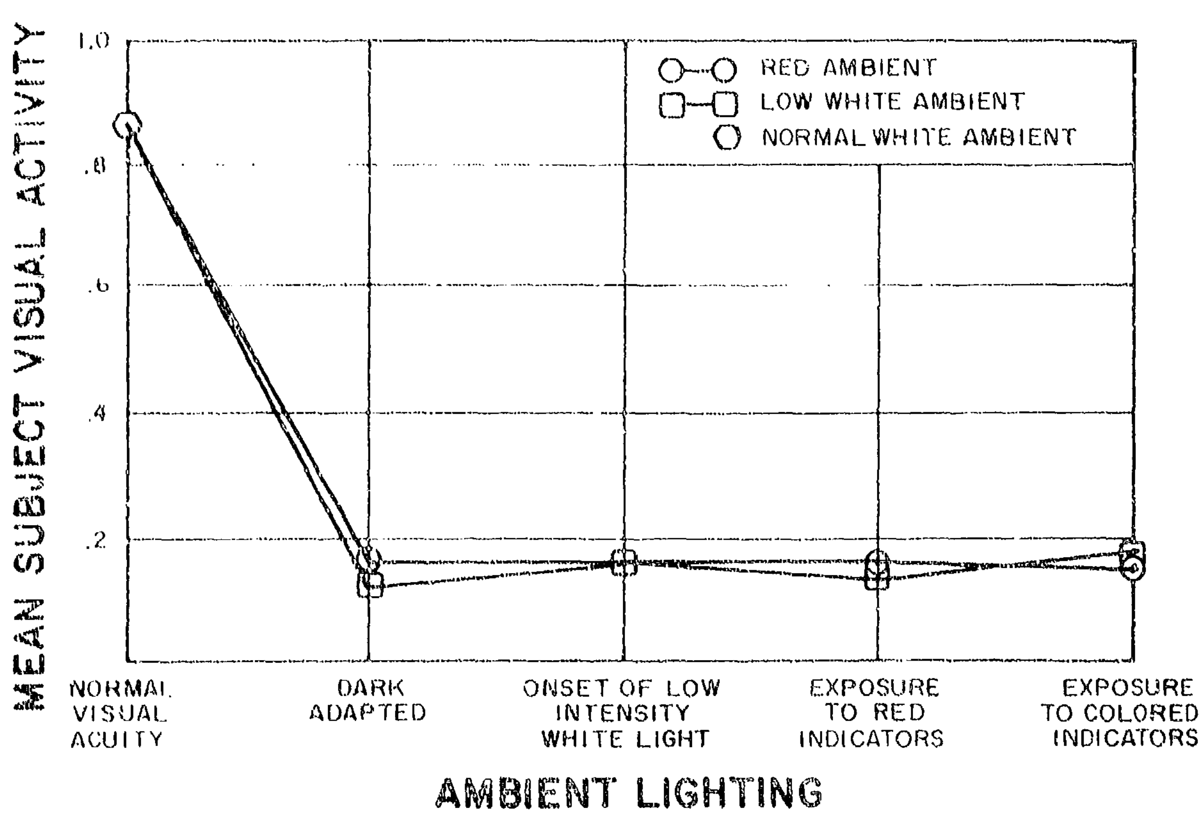

FIGURE 5 MEAN VISUAL ACUITY FOR EACH GROUP OF SUBJECTS UNDER EACH CONDITION OF TESTING

. 02 foot-candles, decreases visual acuity by a factor of approximately 4.5. Visual acuity is approximately the same under the conditions of both nominal white and red ambient illumination. The immediate change from dark adaptation under red ambient to nominal white ambient does not affect visual acuity. Lastly, the utilization of either red or colored display indicator illumination,at the intensities employed in this study does,not affect visual acuity.

4.0 DISCUSSION AND CONCLUSIONS

Red ambient lighting has been used on submarines since World War II as an aid to better vision at night. However, during this time period the mission and capability of the nuclear submarine has changed radically. The nuclear submarine is no longer required to surface frequently at night and, at the same time, the controls, indicators and displays have increased in number and complexity with the increased equipment capability. The utilization of red ambient lighting for dark adaptation has precluded the use of illuminated color-coded indicators and colored pigments as a means of relaying information. The purpose of this study was to obtain quantative data to permit a trade-off between ambient lighting and display screen color illumination for the optimization of display detection without sacrificing dark adaptation.

The results of this study demonstrate that dark adapation is primarily dependent upon the overall illumination level, rather than the red lighting. At the illumination levels required by MIL-E-16400, i.e., 0.02 foot-candles, visual acuity under either red or nominal white ambient is equivalent. However, when compared to a normal white ambient lighting of a submarine control room at 20.0 foot-candles, visual acuity is reduced by a factor of 4.5. Immediately changing from a red ambient to a normal white ambient has no effect on dark-adapted visual acuity. Further, immediately changing from red to colored illuminated display and vice versa also does not affect dark-adapted visual acuity.

A significant difference was found in reaction time among the colors used on the indicator push-buttons under red ambient conditions. The subjects reacted most rapidly to the amber illuminated indicator displays, next to the green illuminated displays, followed by the red illuminated indicator displays and lastly, to the white indicator displays. Since the illuminated indicator display color has no effect upon dark adaptation, the use of these color illuminated indicators would be beneficial for aiding in the detection of GO, NO GO, warning and steady state conditions.

Based upon the results of this study, the ideal set of display and ambient illumination conditions would consist of normal white ambient illumination an. olor-coded

indicator displays for optimal display detection. Since the requirement for dark adaptation within the sonar control room has been firmly established by the Navy to permit the commanding officer, executive officer and conning officer to view the sonar displays when at periscope depth at night, the following alternative approaches in order of precedence are presented.

The most satisfactory set of indicator display and ambient illumination conditions for the retention of dark adaptation would be the utilization of nominal white ambient lighting at the 0.02 foot-candle level, with illuminated color-coded indicator push-button displays. Employing black opaque screens with translucent engraving for push-buttton controls and translucent display screens with black opaque engraving for indicator readouts, is recommended to distinguish between functions. The utilization of black opaque display screens with translucent engraving also reduces the over-all illumination of the display panel.

If low intensity red ambient illumination is to be retained, it is recommended that the illuminated color-coded indicator push-buttons be employed rather than all red-illuminated indicator push-buttons, black opaque display screens with translucent engraving be used on control push-buttons, and translucent display screens with black opaque engraving be used on the indicator readouts to maximize display detection.

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3. MIL-E-16400E Electronic Equipment, Naval Ship and Shore, General Specification For, 10 January 1964.